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Dundalk Sewershed Evaluation Study Plan
Project No. 1047
RJN Job No. 17-2252

I&I Evaluation Report

Sanitary Sewer Overflow Consent Decree
Civil Action No. JFM-02-1524

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Executive Summary

This report describes the work performed to date on the Dundalk Sewershed Inflow and Infiltration (I&I) Evaluation.

The Dundalk Sewershed I&I Evaluation involved flow monitoring, field investigations, and rainfall monitoring. Field investigations consisted of manhole inspections, CCTV, and some smoke testing conducted in the basins DU03, DU05, DU06, and DU07. There was also some smoke testing performed in residential areas of DU02 and DU04. The flow monitoring effort included site investigations to confirm suitable hydraulics for measuring flow in each meter basin. The rain gauges and Sliicer data were utilized to establish rainfall amounts for the preliminary I&I Evaluation. The purpose of the I&I evaluation is to identify significant sources of inflow and infiltration that through rehabilitation will restore capacity to the system and prevent backups and overflows.

The flow and rainfall monitoring period began on this project at the spring of 2006. The Dundalk Collection System and Sewershed Plan project began in August 2007. Most meters were installed in early spring of 2006 and were removed in the spring of 2007. Two meters located outside of City boundaries were installed in the early spring of 2008. These meters and two others lying outside of City boundaries have been left in as permanent meters to monitor flows from the County into the Dundalk Sewershed. Data from the meter period was used to conduct a preliminary basin ranking based on estimated inflow rates per lineal feet of sewer for the purpose of prioritizing additional source investigative work. As a result, additional field investigative work is being performed in basins DU03, DU05, and DU06. This includes smoke and dye testing. These activities will provide additional information useful to complete the analysis and further identify specific areas requiring rehabilitation.

Inspections were carried out for all pipes greater than or equal to 8 inches in diameter and for 850 manholes within the Dundalk sewershed. This report provides details and results of I&I evaluation to date. The results of all source investigative work and the infiltration/inflow evaluation will be included in the final sewershed plan.

In summary, the conclusions and recommendations thus far are as follows:

1. Flow monitoring found 4.1 MGD of inflow and 2.2 MGD of base infiltration in the system.

2. The County contributed 19% of the total inflow and 40% of the total infiltration.

1.0 Introduction

1.1 Sewershed Description

The Dundalk sewershed, shown in **Figure 1-1** at the end of this section, is generally bounded by Eastern Avenue to the north, Inner Harbor to the south, Baltimore City/Baltimore County line (Central Avenue) to the east, and Newkirk Avenue to the west. Interstate 95 runs along the northwest border of the sewershed.

The Dundalk sewershed is about 2500 acres in size with approximately 153,000 linear feet of pipe ranging in diameter from 8-inch to 66-inch, 600 manholes, and one pump station. The covered area is generally a combination of residential and commercial property with a heavy industrial component and the sewage discharges to one outfall of the sewershed. The entire area drains to the Dundalk Pump Station, which discharges to the Outfall Sewershed at one location before being treated at the City's Back River Wastewater Treatment Facility.

1.2 Objectives of Study

The City established two main objectives for the Comprehensive Flow Monitoring Program:

1. Collect accurate rainfall and flow data – The program would accomplish this goal by requiring:

    - The use of the latest metering technology and Doppler radar rainfall measurement.

    - Daily data collection using wireless communication, which identifies equipment malfunctions sooner and, therefore, maximizes rainfall and flow data availability.

    - A multi-tier data processing and data quality assurance by the service providers and the City.

2. Standardize Infiltration and Inflow evaluation – This goal would be accomplished by:

    - Establishing standard Infiltration and Inflow evaluation parameters and definitions for the use of all Sewershed Consultants.

    - Requiring all Sewershed Consultants to use a standard Infiltration and Inflow evaluation software (Sliicer.com®, a registered mark of ADS Corporation).

1.3 Recently Completed Sanitary Projects

The conditions when the flow and rainfall monitoring were completed in the Dundalk sewershed are considered as the baseline conditions. There were no Paragraph 8 projects in the Dundalk sewershed.

1.4 BaSES Manual Requirements

The Baltimore Sewer Evaluation Standards Manual (BaSES), developed by the City for the sewershed studies, establishes guidelines for the Infiltration and Inflow analyses and outlines additional requirements.

2.0 Flow Monitoring Program

2.1 Overall Description

To fully understand the dynamics of the sewage collection system, the City completed a detailed City-wide monitoring program. The program consisted of flow meters within the City's collection system and rain gauges spread throughout the City and County. The monitors measured depth and velocity, from which flow was calculated at five minute intervals. The monitoring program consisted of over 350 flow monitors City0wide with 12 meters within the Dundalk sewershed from May 9, 2006 to May 18, 2007. Some meters deemed long term meters have stayed in place. See **Table 1**, located on the following page, for a list of meters, their sub-basin, purpose, and installation history. **Figure 2-1**, located at the end of this section, depicts a schematic of the monitoring plan. See **Figure 2-2**, located at the end of this section, for a location map of the meters and rain gauges. In addition to the flow monitors, 20 rain gauges were installed City-wide with some gauges installed outside of the City limits. All 20 rain gauges were utilized in conjunction with the generated radar rainfall for analysis.

Table 1
Dundalk Sewershed Infiltration/Inflow Report: Flow Monitoring Program
Flow Meter Summary

Meter	Sub-basin	Purpose	Installation History	
			Installation Date	Removal Date
DU01	DU01	I/I Evaluation and Model Calibration	Friday, March 31, 2006	March-07
DU02	DU02	I/I Evaluation and Model Calibration	Thursday, January 19, 2006	March-07
DU03	DU03	I/I Evaluation and Model Calibration	Tuesday, March 07, 2006	March-07
DU04	DU04	I/I Evaluation and Model Calibration	Thursday, April 06, 2006	March-07
DU05	DU05	I/I Evaluation and Model Calibration	Monday, January 09, 2006	March-07
DU06	DU06	I/I Evaluation and Model Calibration	Monday, January 09, 2006	March-07
DU07	DU07	I/I Evaluation and Model Calibration	Wednesday, January 18, 2006	March-07
BDU01	BDU01	I/I Evaluation and Model Calibration	Wednesday, January 18, 2006	Permanent
BDU02	BDU02	I/I Evaluation and Model Calibration	Wednesday, January 18, 2006	Permanent
BDU03	BDU03	I/I Evaluation and Model Calibration	Friday, February 29, 2008	Permanent
BDU04	BDU04	I/I Evaluation and Model Calibration	Friday, February 29, 2008	Permanent
TSDU03	6301 Lombard	I/I Evaluation and Model Calibration	Wednesday, May 17, 2006	Permanent

2.2 Summary Description of the Metering Network Within the Sewershed

The 12 flow-monitoring sites within the Dundalk Sewershed were selected depending on the use of the flow data. All of the sites were used for the infiltration and inflow evaluation and the calibration of the hydraulic model. Table 1 lists the meters and their primary purpose and installation history. Using the City's Geographical Information System (GIS), the metering sites for the I&I evaluation were selected at a meter density approximately one for ever 25,000 linear feet of sewer pipe. Figure 2-1 is a flow schematic of the meter network within the Dundalk Sewershed. Site reports are included in **Appendix A**, found on the CD provided, and show the manhole identities, hydraulic assessments, proposed equipment, details on installation arrangements, manhole dimensions, pipe shape, location coordinates and special considerations such as safety and traffic control.

2.3 Flow Metering

2.3.1 Equipment Description

The meters used for the City-wide flow Monitoring Program were depth-velocity meters designed to calculate flow based on measured depths and velocities in sanitary sewer pipes under free-flow and surcharged conditions. The primary depth sensor is ultrasonic with resolution to the nearest 0.01 foot. The meters have level measurement redundancy, in the form of a pressure sensor, with accuracy of ±0.25 percent of full scale. The project required that the primary velocity sensor use Doppler technology, capable of measuring flow velocities in the range between -5 to +15 feet per second. The sensors were securely attached to the pipe by means of metal bands or anchoring hardware designed specifically for that purpose.

2.3.2 Installation

Every flow monitoring location was verified by the flow monitoring Contractor by performing a thorough site investigation, including descending the manhole. The hydraulic conditions at each site dictated the metering equipment selection and optimal sensor placement. If a location was deemed unsuitable for flow monitoring, the Contractor was required to coordinate with the City and to investigate up to two alternative sites for consideration. The Contractor also checked for debris in the manhole that could impact data quality. For each location the Contractor prepared and submitted an electronic site investigation report, which included a general site location map, a sketch of the installation, the physical characteristics (diameter or other measurements as necessary to define the pipe cross-section, material, etc.) of the sewer pipe in which the sensors would be installed, manhole depth, and other comments deemed pertinent. In addition, survey-grade GPS (Maryland State Plane ±0.5 inch) coordinates, pipe inverts, and rim elevations; and three digital images of the site were required, including one showing the sensor installation.

The Contractor was required to evaluate the level of silt and debris at each monitoring location, and to provide sewer cleaning to ensure accuracy and reliability at each metering site. In case of odd-shape pipes, or in sites where debris or sediment was present, the Contractor developed a profile and accurately determined the cross sectional area of the pipe at the depth-measuring point. A typical flow monitor installation included the primary ultrasonic depth sensor mounted in the invert, and a Doppler primary velocity sensor mounted in or near the invert of the pipe. All flow meters and rain gauges were synchronized in time to the same clock, and programmed to collect depth and velocity data at five minute intervals.

Upon installation and activation of each flow meter, the Contractor took manual depth and velocity readings using an independent instrumentation to confirm that the in-situ monitor yielded data representative of actual field conditions. The field crews were required to take manual velocity readings of the cross-section (velocity profile) of the flow in order to determine the pipe hydraulic profile.

2.4 Rainfall Measurement

The Contractor was required to measure the contribution from rainfall to all sewershed within the City's jurisdiction boundary using a network of rain gauge stations with a minimum coverage of one rain gauge per ten square miles, as well as data compiled by Doppler radar utilizing a minimum resolution of one pixel per four square kilometers. To measure the contribution from rainfall occurring in portion of the Collection System outside Baltimore City limits, the Contractor installed additional rain gauges outside the City limits.

2.4.1 Equipment Description

The equipment consisted of a data logger able to accept data from and industry standard rain tipping bucket. The equipment was able to measure 0.1 inches (1mm) per tip of bucket. The tipping bucket consisted of a corrosion resistant funnel collector with tipping bucket assembly.

2.4.2 Installation

Most rain gauges were installed on the roof of public schools in the City and the County, and facilities owned by the city's Department of Public Works (such as pump station and treatment plants). One rain gauge was installed within the Dundalk Sewershed, located on the roof of the Dundalk Middle School, 4700 Dunman Way.

2.4.3 Radar Rainfall

In accordance with the requirements of the Consent Decree, the City performed Doppler Radar Rainfall Analysis in conjunction with rain gauges at a resolution of one gauge for every ten square miles. RJN utilized the CALAMAR software platform to process each recorded rainfall event with an average total depth of greater than 0.5 inches of rain. CALAMAR is a tool used to study the hydraulic impacts of precipitation through a combination of radar images and a network of rain gauges installed over a geographic area. CALAMAR uses three databases: a radar image database, a rain gauge database, and a geographical database. After collecting the rain gauge network data and the radar images, CALAMAR produces a model that provides geographically accurate, integrated rainfall intensity data for any predefined area. The Baltimore City geographical area was divided into one square kilometer pixels, and for every significant rain event, Doppler radar rainfall images were generated for every pixel within the Back River and Patapsco wastewater treatment plant service areas. There were a total of 29 storms were during the primary flow monitoring period. The dates of those storm events and the event details are listed in **Table 2**.

Table 2

Dundalk Sewershed Infiltration/Inflow Report: Inflow & Infiltration Evaluation

Storm Event Summary

Rainfall Event	Time of Peak Intensity	60-min Peak Intensity (in/hr)	Total Duration (hr:min)	Total Rain (in)
Thursday, May 11, 2006	7:45:00 PM	4.080	9:50	1.23
Sunday, May 14, 2006	12:05:00 AM	0.960	1:45	0.37
Friday, June 02, 2006	10:20:00 PM	2.880	1:30	1.18
Monday, June 19, 2006	3:30:00 PM	0.960	0:10	0.22
Saturday, June 24, 2006	8:05:00 PM	0.240	2:40	0.36
Sunday, June 25, 2006	8:55:00 PM	2.520	22:20	6.71
Wednesday, July 05, 2006	10:40:00 PM	1.920	5:50	2.17
Saturday, July 22, 2006	6:15:00 PM	2.040	5:20	0.84
Friday, September 01, 2006	8:00:00 PM	0.480	28:55	3.02
Tuesday, September 05, 2006	8:20:00 AM	1.320	13:55	1.82
Thursday, September 14, 2006	4:45:00 AM	0.720	16:50	1.71
Thursday, September 28, 2006	5:40:00 PM	1.920	4:15	0.80
Thursday, October 05, 2006	9:30:00 PM	0.480	1:55	1.73
Tuesday, October 17, 2006	10:30:00 AM	0.360	7:40	0.79
Friday, October 20, 2006	12:35:00 AM	0.840	8:30	0.64
Saturday, October 28, 2006	5:30:00 AM	2.640	16:45	2.01
Wednesday, November 08, 2006	3:55:00 AM	0.600	15:00	1.47
Thursday, November 16, 2006	4:00:00 PM	3.120	47:45	2.06
Wednesday, November 22, 2006	4:30:00 PM	0.240	8:30	1.03
Friday, December 22, 2006	11:50:00 PM	0.360	14:20	1.05
Monday, December 25, 2006	12:55:00 PM	0.240	10:10	0.6

Sunday, December 31, 2006	4:30:00 AM	0.840	14:10	1.06
Sunday, January 07, 2007	7:55:00 PM	0.240	8:10	0.8
Thursday, March 01, 2007	4:05:00 AM	0.360	22:45	0.85
Thursday, March 15, 2007	5:20:00 PM	0.360	23:55	2.69
Friday, March 23, 2007	3:30:00 PM	0.120	17:50	0.35
Wednesday, April 04, 2007	5:10:00 AM	1.200	5:15	0.77
Wednesday, April 11, 2007	2:50:00 AM	0.600	7:35	1.17
Saturday, April 14, 2007	4:10:00 AM	0.240	31:10	2.92

2.5 Groundwater Measurement

The Contractor installed groundwater gauges at 33 flow monitoring sites designated by the City. Each groundwater gauge consisted of a conduit (preferably a clear flexible tube) of sufficient diameter to accommodate a pressure sensor. The pressure sensor was calibrated prior to installation.

2.5.1 Equipment and Installation

The groundwater gauge connected through the manhole wall to the ground around the manhole near the bench of the manhole. The conduit was secured around the manhole wall or steps and extended vertically to a point 6 inches below the manhole lid. The connection through the manhole consisted of a drilled hole no larger than 1.25 inches in diameter, through which a PVC or metal pipe extended to approximately 6.0 inches outside the manhole and into the ground. At the end of this PVC or metal pipe a fine mesh was installed to let groundwater through but keep dirt and debris from clogging the pipe. The space between the manhole wall and the PVC or metal pipe was water-tight sealed with silicon caulking or similar material. The conduit connected securely to the PVC or metal pipe with the proper fittings and hardware to provide a water-tight connection.

2.6 Data Collection and Processing

The Contractor was required to use a host software support application program for remote wireless data collection of all flow meters, rain gauges, and ground water gauges. The host software maintained clock synchronization with the host system’s clock for all field RTUs, thus insuring time interval integrity for all collected data. The City required the Contractor to use a system employing client/server architecture, capable of storing all project deliverables including flow and rainfall data; equipment configurations; event logs; and site parameters into a SQL database. The software allowed any networked computer (with the appropriate access rights) access to the data stored in the SQL database using a common web browser (e.g. Microsoft Internet Explorer). The web module was read only in order to protect data integrity, and had the ability to present near-real time data. Field data measurements could be forwarded to the server immediately following collection by the field RTUs, and the server could immediately post the data to the web site for viewing by authorized parties.

The Contractor was required to employ trained data analysts experienced in processing and analyzing flow and rainfall data from sanitary sewer systems. Various analytical tools, such as hydrographs, scattergraphs, and flow balancing methods were used to verify the accuracy and precision of the flow data. Data collection was performed remotely at least twice a week and was scheduled in a manner to allow data review by a trained data analyst within 24-hours of the data collection. The analyst assessed any maintenance or monitor performance issues, and a crew was dispatched within 48 hours, and the issue resolved within 72 hours from the time the issue was identified. All measurements, adjustments, and efforts undertaken during site visits were logged in an installation/maintenance log specific to that installation.

2.7 Monitoring Period

The period of flow metering extended from May 9, 2006 to May 18, 2007. Some meters deemed long term meters have stayed in place. See Table 1 for a list of meters, their sub-basin, purpose, and installation history.

2.8 Equipment Operation, Maintenance, and Uptime

RJN's qualified field crews visited each monitor installation as appropriate to perform any necessary maintenance to the equipment. As stated above, field crews were dispatched within 48 hours and any O&M issue was resolved within 72 hours from the time the issue was identified. RJN was required to collect useable flow data a minimum of 90% of the time throughout the monitoring period, and to submit to the City an "Uptime" table each month demonstrating compliance with the uptime requirement.

The uptime requirement would be generally satisfied with actual measured data. However, in instances where a velocity measurement was not available, inferred velocity from a reliable depth measurement would not be considered downtime if The Contractor demonstrated that accurate data could be obtained without the velocity measurement, and that the loss of velocity data was not caused by maintenance neglect. In any case, however, no velocity could be inferred for any measurement interval where (1) a corresponding depth measurement has not been obtained for that measurement interval or (2) independent calibration measurements have not been acquired for the site. The Contractor was required to identify all inferred velocity data or other data derived from inferred data in all reports and deliverables.

3.0 Infiltration/Inflow Evaluation

3.1 Sliicer.com Wet Weather Analysis Tool

Sliicer is a tool developed by ADS Environmental Services, Inc. to find the locations of the worst inflow/infiltration problems in a sanitary sewer collection system using rainfall and flow data. By itself in its raw form, flow data can be difficult to interpret. The purpose of Sliicer is to make interpreting flow data easier, so that conclusions about what to do to enhance the performance of the collection system can be developed. Sliicer also allows the user to integrate flow data with physical inspection data to find the best approach to fixing the collection system. Finally, Sliicer generates the flow components necessary to calibrate the hydraulic model.

3.2 Global Setting

Global Settings are Sliicer parameters established by the City to be used by all Sewershed Consultants. These parameters should not be changed and will provide a necessary degree of standardization. Global settings include:

- The average dry day flow normalized by the linear feet contained in each sub-basin.
- The time step averaging will be 30 minutes.
- Criteria for defining dry days and which days should be excluded.
- Two seasons will be considered: Eastern Daylight Time and Eastern Standard Time.
- The threshold for a rain event to be considered in the analysis is 0.5 inches in 24 hours.
- The default method for computing wastewater production will be the Stevens-Schutzbach Method.
- The rolling method will be used for rainfall peaks.
- The units used are million gallons per day for flow rates, million gallons for volume, feet per second for velocity, and inches for flow depth.

3.3 Dry Day Analysis

3.3.1 Dry Day Selection

Following the criteria established within the BaSES Manual, dry days were defined according to **Table 3**:

Table 3 Dundalk Sewershed Infiltration/Inflow Report: Inflow & Infiltration Evaluation Criteria for Dry Days	
Number of Prior Days	Cumulative Antecedent Rain (Inches)
1	0.1
3	0.4
5	1.0

In addition, dry days with total flows that are 15 percent higher or lower than the average volume of all dry day were excluded from the analysis. Next the dry day traces for each meter were edited to remove any outliers that may have passed through the filtering requirements. Finally, Sliicer calculated the Average Dry Flow (ADF) from all the traces.

3.3.2 Dry Day Groups

The dry-day groups used were weekdays and weekends. The weekdays include Mondays through Fridays. The weekends include Saturdays and Sundays.

3.3.3 Season Groups

The seasons used for the study were Eastern Daylight Saving Time (DST) and Eastern Standard Time (EST).

3.3.4 Wastewater Production and Base Infiltration Components

The wastewater production (WWP) was calculated by subtracting the base infiltration (BI) from the average dry flow (ADF). As required, the Stevens-Schutzbach Method was used to determine the base infiltration. The Stevens-Schutzbach Method is as follows:

$$BaseInfiltration = \frac{0.4 \times MDF}{\left(1 - \left(0.6 \times \left(MDF / ADF\right)^{(MDF)^{0.7}}\right)\right)}$$

Where: MDF = minimum dry flow

The gross infiltration rate was used for basins that exhibited negative net infiltration. Please see Section 4 of this report for the results of the dry-weather analysis.

3.3.5 Base Infiltration Normalization by IDM

Normalizing BI is important when comparing basin with severe infiltration problems. Simply looking at infiltration rates does not always lead to the right conclusion about the location of the worst problems in the collection system. For this project, BI was normalized based on inch-diameter-miles (IDM). The IDM normalization was selected for BI because it takes into account not only the length, but also the diameter of the pipes in the basin. Regardless of the length, the larger the pipe diameter the more pipe surface is exposed to groundwater. Sliicer provides this type of BI normalization for each basin.

3.4 Wet Weather Analysis

3.4.1 Global Storms

A total of 29 storms during the metering period met the criteria for a storm event as defined by the global setting. The dates of these storms are listed in Table 2. Each storm was analyzed for each flow meter using the Sliicer.com software.

3.4.2 Pre-Compensation Period

For each storm, a pre-composition period (typically 24 hours prior to the storm event) was established to adjust the dry day hydrograph to match the actual hydrograph immediately prior to the start of the storm. This either raises or lowers the dry day hydrograph so that the calculated rainfall-dependent infiltration and inflow (RDII) is a result of the storm event only.

3.4.3 Storm Measurement Periods

Sliicer.com calculates I&I for three periods following the start of the storm. They are called Storm, Recovery 1 and Recovery 2. Each period by default is 24 hours long which is set by the global settings. For this project, however, the storm periods were set by the City, are specific for each storm, and are long enough to capture all the RDII. The recovery periods 1 and 2 were set to 60 minutes, but are not used in any calculations.

3.4.4 RDII Calculations

In order to estimate the RDII, Sliicer over-imposes the typical dry-day hydrograph on the storm hydrograph. The difference between the two hydrographs represents the RDII.

3.4.5 RDII Normalization

3.4.5.1 By Linear Footage of Pipe

Normalizing the RDII is extremely important when comparing results to find the worst basins. Simply looking for the most raw wet weather flow does not always lead to the right conclusion about the location of the worst I&I problems in the collection system. Although raw I&I information is part of the picture, it needs to be correlated with basin size and rainfall information before it becomes useful. For this project, RDII was normalized based on linear footage (gal/l.f./in-of-rain). Sliicer provides this type of normalization for each meter for each storm. The average of all storms was calculated.

3.4.5.2 By Area (Capture Coefficient)

A graphical technique for evaluating and comparing the performance of sewershed basins under widely varying rain events is the ***Q*** vs. ***i*** diagram. ***Q*** is the calculated I&I for a storm and i is the corresponding rainfall. The slope, S, of the regression line on the ***Q*** vs. ***i*** plot was used in the following equation to obtain the capture coefficient, R.

$$R = (36.83_{\text{(acres-in/mg)}} * S_{\text{(mg/in)}}) / \text{Area}_{\text{(acres)}}$$

The capture coefficient represents the percentage of the volume of rain water that fell on the basin that found its way into the collection system. ***Q*** vs. ***i*** plots for each flow meter are included in **Appendix B** found on the CD provided.

4.0 Evaluation Results

Dundalk sewershed was evaluated under dry weather conditions in order to find the levels of base infiltration without the added affect of rain. These permanent infiltration estimates will be compared to the model results to ensure accuracy. Using the Stevens-Schutzbach Method and normalizing the BI rates by inch-diameter-mile, the basins were ranked from highest severity to lowest severity: DU03, DU04, DU06, DU07, DU05, DU02, and DU01. Gauges BDU01, BDU02, BDU03, and BDU04 monitor the BI from the County. Based on the calculations the total BI rate is 34,627 gpd/idm and the County contributes approximately 40% of that.

The wet weather analysis provides a look at the inflow entering the system through private sectors as well as catch basins, storm ditches, manhole defects, and storm sewer and sanitary sewer cross connections. The capture coefficient was calculated from the Q vs. i graphs and then normalized by linear foot. The basins were ranked from most severe RDII to least severe RDII: DU05, DU06, DU01, DU03, DU07, DU04, and DU02. Gauges BDU01, BDU02, BDU03, and BDU04 monitor the RDII from the County. Based on the calculations the total RDII rate is 190 Gal/l.f./in-of-rain and the County contributes approximately 19% of that.

4.1 Dry Day Results

Peak infiltration is defined as the maximum extraneous flow that enters the sanitary sewer system during high groundwater conditions after the effects of rainfall inflow have ended. Infiltration enters the sanitary sewer through pipe joints, sewer line defects (including main sewer lines and service laterals), and defective manhole walls, benches, and pipe seals. Dry weather flow is defined as wastewater flow exclusive of peak infiltration or inflow. Dry days are days when there were only minor storms may occur in weeks prior and groundwater levels are not affected by rain.

The dry weather flows obtained during this study are believed to represent an extreme condition due to the drought conditions that occurred in the area during this time period, specifically in 2007. **Table 4** includes the net average dry weather flow at each meter basin during the selected dry period for both weekdays and weekends.

Table 4
Dundalk Sewershed Infiltration/Inflow Report: Evaluation Results
Net Average Dry Weather Flows

Meter Basin	Average Flow (mgd)					
	2006		2007			
	DST Weekday	DST Weekend	EST Weekday	EST Weekend	DST Weekday	DST Weekend
DU01	0.084	0.050	0.161	0.013	0.477	0.373
DU02	0.095	0.083	0.055	0.069	0.000	0.001
DU03	0.603	0.591	0.652	0.643	0.579	0.568

DU04	0.271	0.193	0.338	0.248	0.364	0.321
DU05	2.167	2.295	2.198	2.258	2.134	2.076
DU06	0.471	0.401	0.534	0.494	0.470	0.435
DU07	0.290	0.327	0.299	0.351	0.329	0.419
BDU01	0.251	0.270	0.317	0.321	0.438	0.446
BDU02	0.148	0.157	0.155	0.165	0.155	0.173
	2008 DST Weekday			2008 DST Weekend		
BDU03	0.932			0.828		
BDU04	1.069			1.135		

Note: BDU03 and BDU04 were installed in the Spring of 2008 and therefore only have data for Daylight Saving Time 2008.

The summer analysis provides permanent infiltration estimates for comparison with model results whereas the winter analysis provides peak infiltration as defined above. Base infiltration (BI) was calculated in Sliicer using the Stevens-Schutzbach Method. Please refer to page 3-4 under the Wastewater Production and Base Infiltration section of this report for the method equation. The wastewater production is calculated by subtracting the BI from the ADF. This calculation does not represent added infiltration that occurs under temporary, high groundwater conditions produced under rainfall referred to as Rain Dependent Inflow/Infiltration (RDII).

To compare base infiltration severity among basins of different sizes, a unit infiltration rate was calculated based on peak infiltration. The size of a meter basin is defined by the tributary length and corresponding pipe diameters. The pipe lengths were derived from the sewer GIS data provided by the City of Baltimore. To determine basin size relative to others, each basin was measured inch-diameter-mile (idm). The BI rates were then normalized by inch-diameter-mile to provide a more accurate picture of the severity of each basin. The percentage of the ADF that was due to BI was also calculated. Based on the normalized BI rates, the sub-basin ranking from highest severity to lowest severity is: DU03, DU04, DU06, DU07, DU05, DU02, and DU01. The worst basins, DU03, DU04, and DU06 had BI severity (gpd/idm) values of 8,564, 6,322, and 3,692, respectively. The sewershed's total BI rate is 0.86 MGD or 20,954 gpd/idm.

These calculations do not reflect the BI contributions from Baltimore County. That data is collected by meters BDU01, BDU02, BDU03, and BDU04. Together these basins contribute approximately 13,600 gpd/idm of BI and the total BI rate becomes 34,627 gpd/idm or 2.2 MGD. The County contributes approximately 40% of the total BI for the Dundalk sewershed. Negative net flows were observed for TSDU03 and a negative BI was calculated in Sliicer. Although the negative BI implies ex-filtration, this is most likely a result of issues with meter data and balance. Therefore, no BI contribution was assigned to TSDU03.

The complete analysis for base infiltration estimated during summer dry weather is provided in **Table 5,** including normalized BI rates for each basin**. Figure 4-1**, located at the end of this section, shows a map of the Dundalk sewershed with the base infiltration basin rankings. The analysis considers both gross flows and net flows, when indicated, for each site. For sites with incoming flow that is measured at another meter upstream, a net flow computation is performed. This balancing of flows is performed to insure that individual meter results are reasonable relative to each other. Net flows represent only the flows within a meter basin not previously measured by any other upstream meter. The summer dry weather evaluation was used to compare meter data infiltration results with model data.

Table 5
Dundalk Sewershed Inflow/Infiltration Report: Evaluation Results
Dry Weather Analysis - DST 2006 - Weekdays Only

Basin	Agross (acres)	Anet (acres)	Anet/Agross (%)	IDM (in-dia-mile)	ADFgross (MGD)	ADF (MGD)	Qnet/Qgross (%)	WWP (MGD)	BInet (MGD)	BI Severity (gpd/idm)	BI Rate (%)	WWP Rate (gln/l.f.)
DU01	1233	739	0.60	109.8	0.764	0.084	0.11	0.083	0.001	9.1	0.012	2.9
DU02	494	289	0.58	49.1	0.698	0.095	0.14	0.091	0.004	81.5	0.042	4.4
DU03	206	206	1.00	38.3	0.603	0.604	1.00	0.276	0.328	8564.0	0.543	11.3
DU04	152	152	1.00	31.0	0.271	0.270	1.00	0.074	0.196	6322.6	0.726	3.7
DU05	2345	445	0.19	65.9	3.327	0.274	0.08	0.266	0.008	121.4	0.029	11.6
DU06	775	167	0.22	53.9	1.160	0.471	0.41	0.272	0.199	3692.0	0.423	9.7
DU07	463	263	0.57	55.0	0.438	0.290	0.66	0.171	0.119	2163.6	0.410	5.7
BDU01	145	145	1.00	36.4	0.251	0.251	1.00	0.107	0.144	3956.0	0.574	4.9
BDU02	199	199	1.00	42.6	0.148	0.148	1.00	0.078	0.070	1643.2	0.473	2.9
BDU03	272	272	1.00	91.4	0.826	0.826	1.00	0.366	0.460	5032.8	0.557	6.5
BDU04	853	853	1.00	206.2	1.069	1.069	1.00	0.441	0.627	3040.7	0.587	3.5
TSDU03	3823	92	0.024	87.7	4.104	0.085	0.02	0.085	0.000	0.0	0.000	6.9

4.2 Wet Weather Results

Inflow in a sanitary sewer system is defined as extraneous flow that is a direct result of stormwater runoff. Inflow may enter the sanitary sewer through numerous sources in the private sector such as downspouts, area drains, and service lateral cleanouts. In the public sector, inflow enters the sewer system through sources such as cross connections between the sanitary sewers and storm sewers, catch basins, and storm ditches; and sources such as manhole defects at the cover, frame seal, and corbel area.

The relationship of monitored RDII volume and rainfall depth was analyzed for many storm events. This is referred to as a ***Q*** versus ***i*** analysis, where ***Q*** is the RDII flow volume and ***i*** is the corresponding rainfall. A statistical relationship can be established that is useful for predicting inflow volumes expected from higher intensity storms from analysis of a series of lower intensity events. The nature of this analysis is described in more detail in **Appendix C** found on the provided CD. The ***Q*** versus ***i*** analysis for all sites are provided in Appendix B.

From the ***Q*** versus ***i*** plots, the capture coefficient, R, can be calculated. The capture coefficient is the percentage of the volume of rain water that fell on the basin and entered the collection system. Please refer to page 3-5 under the RDII Normalization by Area section of this report for the method equation to calculate R.

Each basin's RDII values were normalized by linear foot. Based on these calculations the basin ranking, most severe to least severe RDII, is: DU05, DU06, DU01, DU03, DU07, DU04, and DU02. DU05 had the highest amount of RDII at 54 Gal/l.f./in-of-rain. DU02 had the least amount of RDII at 3.9 Gal/l.f./in-of-rain. **Table 6** shows a complete list of each basin's RDII values and capture coefficients. The sewershed's total RDII is 125 Gal/l.f./in-of-rain. **Figure 4-2**, located at the end of this section, shows a map of the Dundalk sewershed with the rain dependent infiltration basin rankings.

Table 6
Dundalk Sewershed Inflow/Infiltration Report: Evaluation Results
Wet Weather Analysis

Basin	RDII (Gal/l.f. - in)	Winter Capture Coefficient, R (%)
DU01	14.84	2.14
DU02	3.90	1.02
DU03	13.00	5.55
DU04	7.60	3.62
DU05	54.00	10.17
DU06	22.00	13.45
DU07	10.29	4.33
BDU01	20.27	11.16
BDU02	5.13	2.59
BDU03	5.20	3.93

BDU04	4.50	2.50
TSDU03	28.00	13.60

Note: RDII and Capture Coefficient of DU05 are normalized to the total area and linear footage of DU05, BDU03, and BDU04

These calculations do not reflect the RDII contributions from Baltimore County or TSDU03. Together these basins contribute approximately 63 Gal/l.f./in-of-rain of RDII and the total RDII rate becomes 188 Gal/l.f./in-of-rain. The County contributes approximately 19% of the total RDII for the Dundalk sewershed. For the complete Flowload database from Sliicer, please refer to **Appendix D** on the CD provided.

Based on the typical meter basin size in this study, metered flow response to peak hourly rainfall ranged from one to two hours. This is consistent with the expected time of concentration within the meter basins and indicates that the selection of peak hourly rainfall provides a suitable parameter to compare with peak flow rate. A regression analysis was performed on the data for all meter sites to establish the "best fit" on the data points with a 90% or higher correlation. Projections were then made to the peak inflow that is anticipated from a 60-minute storm with a 1-year return interval. As stated previously, the confidence in the projections for the 1-year 1-hour storm are affected because the regression line was developed using much lower intensity storms.

The 1-year, 60-minute rainfall intensity for the project area is estimated to be 1.15 inches/hour, as derived from Rainfall Frequency Atlas of the United States, National Weather Service, NOAA 14, 2006. Several storm events of varying intensity were used to establish the rainfall intensity/inflow relationship, however no rainfall events were of the 1-year, 1-hour design storm intensity of 1.15 inches/hour. Periods of surcharging conditions were not used for the analysis because of changed system hydraulics. Under surcharged conditions, overflow may occur and inflow sources may not enter the system at the same rate that they would under free flow conditions in the pipe network. Data from these conditions tends to under predict inflow if used.

The total inflow estimated for the Dundalk Sewershed is 4.1 MGD based on the 1-year, 60-minute design storm. The areas with possible capacity issues and SSOs are DU05, DU06, and DU03. These basins all show I&I rates of greater than 10gal/l.f. The CCTV and manhole inspections verify these suspect basins. The sewers were rated on a scale of 1 through 5 with 5 being the worst. These sewers were the ones recommended for further inspection using smoke testing. DU01 also exhibited I&I rates greater than 10gal/l.f. DU01 consists primarily of large diameter interceptor sewer and therefore is not believed to have a capacity issue, however field inspections show that some manholes have been bolted shut possibly as a result of overflow conditions in the past.

Appendix E, found on the provided CD, provides the scattergraphs and hydrographs for all sites. Based on the data, DU01 is operating under non-uniform flow conditions, generally between 0.5 and 4 MGD. As backwater conditions develop, flow conditions become deeper and slower. DU02 operates under uniform flow conditions, generally between 0.5 and 2MGD. The flow does not exceed 4 MGD. DU03 operates between 0.25 and 4 MGD and varies little in water depth. DU04 operates at less than 1MGD and shows uniform flow conditions. These conditions are most likely due to the basin not having any upstream basins. The data for DU05 shows that the flow operates under uniform flow conditions. However, there is a significant amount of outlier data where the depth within the pipe increases dramatically. As a result the flow operates between 2 and 18 MGD and has some data showing more than 18 MGD. This basin may be a potential SSO, as stated earlier. DU06 also operates under uniform flow conditions, but shows some increased flow depths and operates between 1 and 10 MGD. DU07 is operating under uniform flow conditions at less than 8 MGD. However, as backwater conditions develop, flow conditions become deeper and slower.

The areas from the County that contribute to the City's inflow/infiltrations rates general operate under non-uniform flow conditions. BDU01 is operating under high velocities based on the depth and shows non-uniform flows. The flow remains at less than 2.1 MGD. BDU02 operates under non-uniform flow conditions between 0.05 and 1.4 MGD. BDU03 operates under uniform flow conditions at less than 2.0 MGD. BDU04 operates under non-uniform flow conditions and the flow is between 0.18 MGD and 4.2 MGD.

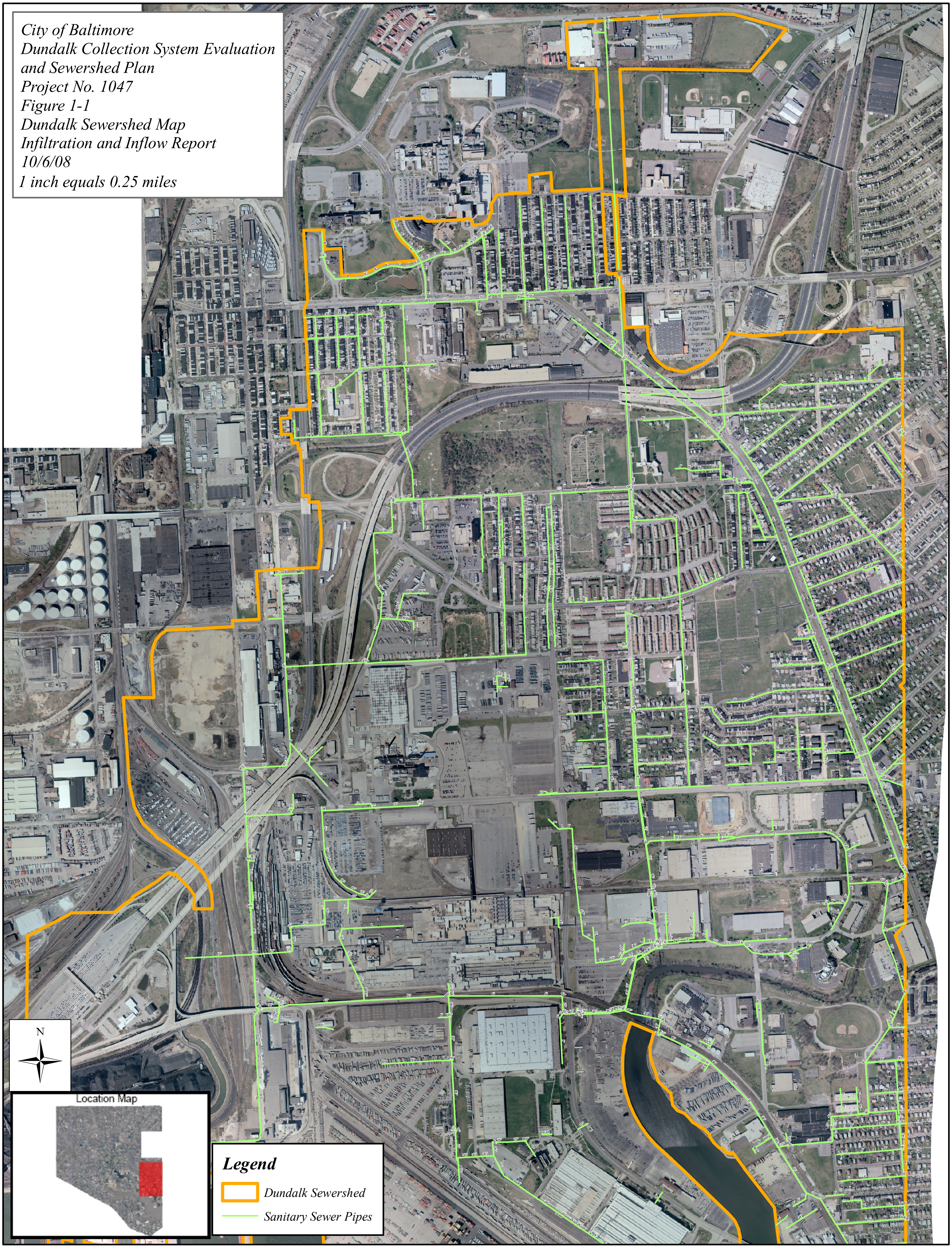
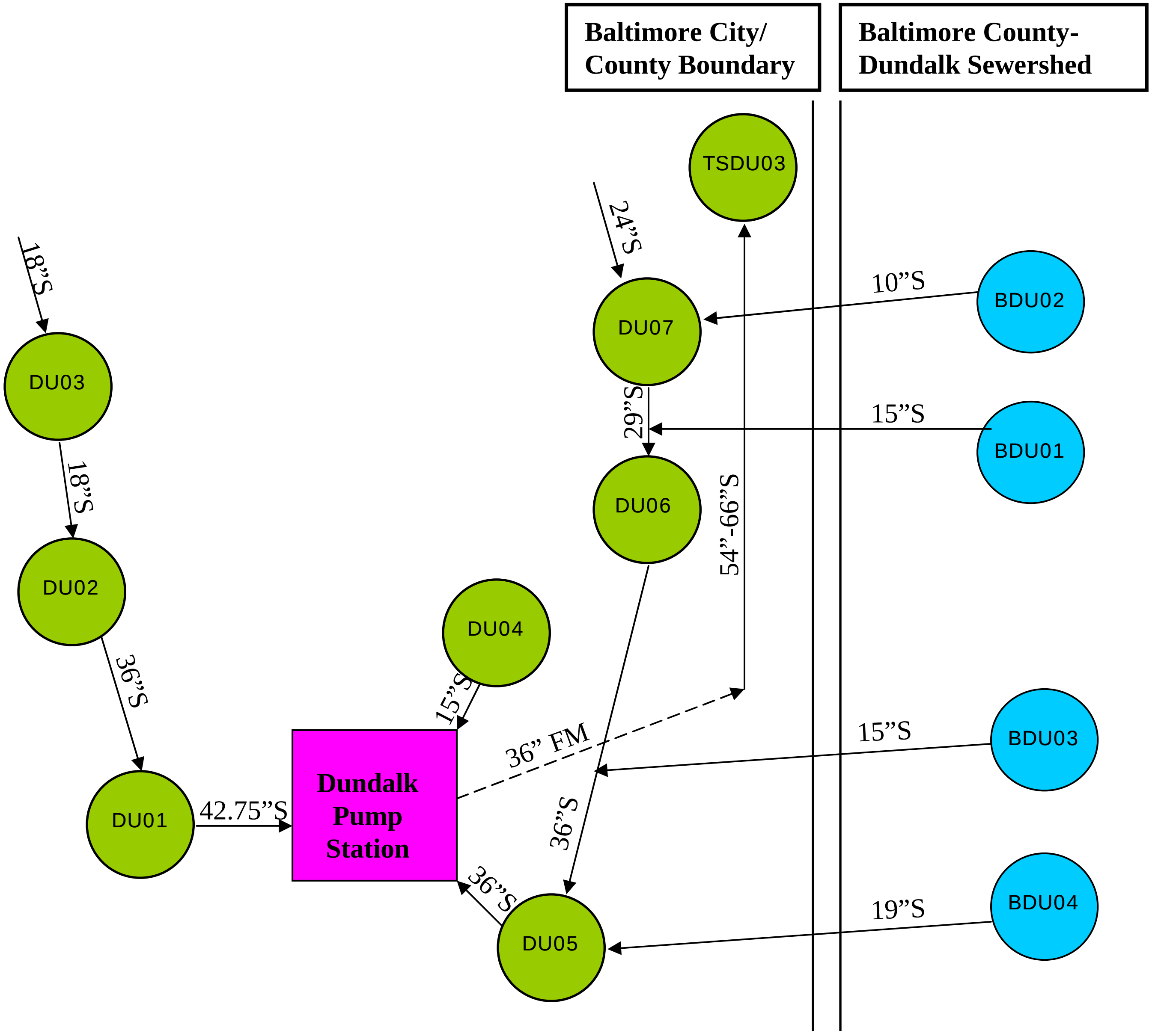

City of Baltimore
Dundalk Collection System Evaluation
and Sewershed Plan
Project No. 1047
Figure 1-1
Dundalk Sewershed Map
Infiltration and Inflow Report
10/6/08
1 inch equals 0.25 miles
N
Location Map
Legend
Dundalk Sewershed
Sanitary Sewer Pipes

Figure 2-1: Dundalk Flow Meter Schematic



City of Baltimore
Dundalk Collection System Evaluation and Sewershed Plan

Project No. 1047

Figure 2-2

Basin, Meter, and Gauge Locations

Infiltration and Inflow Report

3/1/10

1 inch equals 0.1 miles

City of Baltimore
Dundalk Collection System Evaluation and Sewershed Plan
Project No. 1047
Figure 4-1
Base Infiltration Severity Map
Infiltration and Inflow Report
3/1/10
1 inch equals 0.1 miles

City of Baltimore
Dundalk Collection System
Evaluation and Sewershed Plan
Project No. 1047
Figure 4-2
Rain Dependent Inflow/
Infiltration Severity Map
Infiltration and Inflow Report
3/1/10
1 inch equals 0.1 miles